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(54) **Method and system for controlling a DC link voltage of a power converter connecting an electric generator of a wind turbine with a power grid**

Verfahren und System zur Steuerung einer Gleichstromverknüpfungsspannung eines Stromwandlers, der an einem elektrischen Generator einer Windturbine mit einem Stromnetz angeschlossen ist

Procédé et système pour contrôler une tension de lien CC d'un convertisseur de puissance connectant un générateur électrique d'une éolienne avec un réseau électrique

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Description

[0001] The present invention generally relates to the technical field of operating wind turbines. In particular, the present invention generally relates to a method and to a system for controlling a DC link voltage of a power converter connecting an electric generator of a wind turbine with a power grid. The present invention further related to a computer program for carrying out the described method. The document Multi-pole permanent magnet synchronous generator wind turbines' grid support capability in uninterrupted operation during grid faults, IET Renew. Power Giener., 2009, Vol. 3, Iss. 3, pp. 333-348, discloses a wind electric power generation system in which the dc link voltage is controlled in response to mechanical oscillations.

Art Background

[0002] Wind power generation has received a major impetus due to ever increasing demand for energy, depleting fossil fuel reserves and environmental benefits in particular with respect to the emission of greenhouse gases.

[0003] A wind turbine comprises a drive train, which includes all mechanical components, which are in a functional view connected upstream with respect to an electric generator being used for converting mechanical energy/power captured from wind into electric energy/power being supposed to be provided to a power grid. Important drive train components are e.g. rotor blade, a hub, a main shaft and, if applicable, a gearbox.

[0004] When operating a wind turbine regularly mechanical oscillations within the drive train occur. Such oscillations may cause an out-of-round operation of the electric generator which has a negative impact not only on the lifetime of the wind turbine but also on the electric quality of the energy/power being provided by the wind turbine to a power grid. Such mechanical oscillations may be so called "torque oscillations" and/or "speed oscillations". A pure torque oscillation is an oscillation, wherein in the absence of any internal movement of at least one component of the drive train a value for the torque within the at least one component varies over time. A pure speed oscillation is any oscillation, wherein in the absence of torque variations the speed of at least a part of a component of the drive train varies over time. The speed may be in particular a rotational speed, however also a translational or a combination of a translational and a rotational speed is possible. Typically, the variations over time occur periodically.

[0005] In particular in a variable speed wind turbine, mechanical oscillations of drive train and in particular of the rotor blades at resonance frequencies can be excited by grid voltage dips and/or by wind speed changes. Mechanical oscillations resulting from such perturbations can cause a trip of the wind turbine and sometimes even structure damages of components (in particular rotor blades) of the drive train. Therefore, it is necessary to damp mechanical drive train oscillations in particular in variable speed wind turbines.

[0006] A known basic principle for damping such mechanical oscillations is to control the power output of the wind turbine being fed to the power grid at drive train resonance frequencies so that mechanical oscillations at this frequency can be reduced. In this context wind turbine controllers have been proposed, which comprise appropriate electronic hardware and/or software filters being comprised within the controllers. However, when applying this kind of active damping control by means of a dedicated wind turbine controller, power oscillations at the mechanical resonance frequency of components of the drive train are sent to the power grid, which is not preferred in both a steady state operational condition and intermediate operational condition comprising a ride through a grid fault. This has the effect that it is difficult for a wind turbine operator to meet power quality requirements given by the operator of a power grid, which receives electric power from the wind turbine.

[0007] There may be a need for an effective method which allows for reducing mechanical oscillations of a drive train of a wind turbine.

Summary of the Invention

[0008] This need may be met by the subject matter according to the independent claims. Advantageous embodiments of the present invention are described by the dependent claims.

[0009] According to a first aspect of the invention there is provided a method for controlling a DC link voltage of a power converter connecting an electric generator of a wind turbine with a power grid. The provided method comprises (a) determining the rotational speed of a rotor of the electric generator, (b) determining a strength of harmonic components of the rotational speed of the rotor, wherein the harmonic components have frequency components being different from a fundamental rotational frequency of the electric generator, (c) determining a damping reference signal as a function of the determined strength of the harmonic components, and (d) controlling the DC link voltage of the power converter in response to the determined damping reference signal.

[0010] The described control method is based on the idea that by controlling the DC link voltage of a power converter, mechanical oscillations of a wind turbine and in particular mechanical oscillations of a drive train of the wind turbine can be effectively reduced.

[0011] By controlling the DC link voltage in the described manner harmonic power, which is generated by the electric generator in response to unwanted mechanical oscillations of and/or within a drive train of the wind turbine, is not forwarded to the power grid via the power converter. Instead, this generated harmonic power is sent to the DC link of the power converter and in particular to a DC link capacitor of the power converter. Thereby,

a time dependent variation of the DC link voltage arises which has a retroaction to the electric generator. This retroaction causes a mechanical damping capability of the electric generator, which is capable of effectively reducing the mechanical oscillations of and/or within the drive train, which mechanical oscillations represent(ed) the source of the unwanted generation of harmonic power.

[0012] The described damping reference signal may by for instance a damping power reference signal or a damping torque reference signal. In this respect the damping power reference signal represents a reference or nominal value for the actual damping power of the electric generator. Correspondingly, the damping torque reference signal represents a reference or nominal value for the actual damping toque of the electric generator.

[0013] The described determining of the rotational speed may be realized by means of a measurement procedure relying on the output of an appropriate rotational speed sensor, by means of an estimation procedure, wherein at least one input value is used in order to estimate the actual rotational speed at least approximately.

[0014] In this document the term "electric generator" is used for any electromechanical device, which is capable of converting mechanic energy in electric energy. For generating a magnetic field, which in accordance with basic physical principles is necessary for the energy conversion, the electric generator may have current driven coils and/or permanent magnets.

[0015] The term "power converter" may denote any electric power device, which is used for an adaptation of a variable voltage and frequency of the electric generator to a nominally fixed voltage and frequency of a power grid. A power converter includes a generator bridge, which in normal operation operates as an active rectifier in order to supply power to a DC link. The generator bridge can have any suitable topology with a series of semiconductor power switching devices fully controlled and regulated using a pulse width modulation (PWM) strategy. A power converter typically also comprises a network bridge that converts electrical energy between dc link and power grid. Since a power converter always accomplishes a frequency conversion, such power converters are often also denominated as frequency converters.

[0016] The term "DC link voltage" denotes the voltage being present at the above described DC link of the power converter.

[0017] The term "fundamental rotational frequency" may particularly denote the rotational frequency of the rotor of the electric generator, which is associated with a desired operation of the wind turbine in the absence of any mechanical oscillations within the drive train of the wind turbine. Of course, if the electric generator is used in a variable speed wind turbine, which is a preferred application field for the control method described in this document, the fundamental rotational frequency will not be constant over time.

[0018] The drive train includes any mechanical components of a wind turbine, which are in a functional view connected upstream with respect to the electric generator. Important drive train components are e.g. rotor blade, a hub, a main shaft and, if applicable, a gearbox.

[0019] As has already been described above, the harmonic power components are sent to the DC link of the power converter and not to the power grid. This may provide the advantage that grid power harmonics can be reduced effectively.

[0020] The described method is in particular suitable for wind turbines, which depending on the actual wind condition are operated with variable rotational speed of the rotor. In this context the "rotor" may denote the rotor of the wind turbine, which comprises the rotor blades being mounted to the hub, and/or the rotor of the electric generator. The wind turbine may be either a so called direct drive wind turbine, wherein the main shaft of the wind turbine rotor directly drives the electric generator, or a wind turbine comprising a gearbox, which is connected between the main shaft and the electric generator.

[0021] Descriptive speaking, the described control method may be able to damp mechanical drive train and in particular mechanical blade oscillations in a variable speed wind turbine without feeding harmonic power to grid. In order to damp the mechanical oscillation of the drive train/blade, harmonic power at resonance frequencies of drive train/blade is produced by the electrical generator. Instead of sending the produced harmonic power to the power grid, the power converter sends this harmonic power to a DC link capacitor of the DC link of the power converter which will control the respective DC link voltage varying at certain range.

[0022] According to an embodiment of the invention determining the strength of harmonic components of the rotational speed of the rotor comprises (a) receiving a signal being indicative for the actual rotational speed of the rotor and (b) filtering the signal with a filter, which is capable of suppressing at least partially frequency components corresponding to the fundamental rotational frequency. This may provide the advantage that the strength of the harmonic components of the rotational speed of the rotor can be determined easily and in an effective manner.

[0023] The described filter may be realized by means of a hardware (electronic) filter, by means of a software filter or by means of a so called hybrid filter which relies on a combination between software and hardware filtering.

[0024] The described filter may be a single filter or a filter system comprising different single filters. In particular, the described filter may comprise a high pass filter or a band pass filter.

[0025] According to a further embodiment of the invention determining the damping reference signal comprises (a) receiving the filtered signal from the filter and (b) limiting the strength the received filtered signal. This may provide the advantage that it will be ensured that the

strength of the damping reference signal will be kept within technically meaningful limits and an unwanted oversteer of the DC link voltage control can be avoided.

[0026] The range into which the damping reference signal will be restricted can be defined by two limiting values, wherein the absolute value of the two limiting values is the same and the sign of the two limiting values is different.

[0027] In this respect it is mentioned that the step of determining the damping reference signal may optionally further comprise an amplification of the filtered signal with a predefined amplification gain. An appropriate amplifier may be connected preferably in between the filter and a limiting unit, which is configured to perform the described limiting procedure.

[0028] According to a further embodiment of the invention controlling the DC link voltage of the power converter is carried out in further response to the actual DC link voltage. This may provide the advantage a closed loop control is realized, which may allow for an accurate and precise control of the DC link voltage.

[0029] According to a further embodiment of the invention controlling the DC link voltage of the power converter is carried out in further response to a reference signal for the DC link voltage. This may provide the advantage that the accuracy of the DC link voltage can be even further improved.

[0030] According to a further embodiment of the invention the method further comprises filtering a measurement signal being indicative for the actual DC link voltage with a further filter, which is capable of suppressing at least partially frequency components corresponding to mechanical resonance frequencies of a drive train of the wind turbine. Thereby, the frequency components after the filter may be related to the fundamental rotational frequency and/or to harmonics of this fundamental rotational frequency. This may mean that the filter can suppress resonance frequencies/harmonics in the measured dc link voltage. Therefore, compared to the signal before the filter the signal after the filter contains weaker harmonics or less harmonics caused by mechanic resonance frequencies of the wind turbine drive train.

[0031] The further filter may be a band stop filter so that a DC link controller, which is responsible for controlling the DC link voltage, has no response to harmonic voltages being present at the DC link of the power converter. Thereby, the frequency response of the further filter may be preferably designed such that predominately only signal portions having a frequency being in the regime of the fundamental frequency and not within higher frequency regimes can pass the further filter. This may provide the advantage that bandwidth limitations of the DC link controller are removed. As a consequence, the described method will be also applicable for applications wherein the fundamental frequency is relatively high(e.g. higher than 20 Hz).

[0032] According to a further embodiment of the invention controlling the DC link voltage comprises controlling an AC-to-DC conversion being carried out in a generator bridge of the power converter. Thereby, the generator bridge may be controlled by a so caller generator control portion of the power converter controller.

[0033] According to a further embodiment of the invention a reference signal for the amount of power to be generated by the wind turbine is used for controlling a DC-to-AC conversion being carried out in a network bridge.

[0034] In other words, the described control method further takes into account a general power reference for the wind turbine. This may provide the advantage that the described control method may contribute to maintain the amount of power being generated by the wind turbine at a predetermined level, which may be given for instance by a superordinate wind farm controller controlling the general operation of a plurality of wind turbines of a wind farm.

[0035] According to a further embodiment of the invention controlling the DC link voltage comprises controlling a DC-to-AC conversion being carried out in a network bridge of the power converter. Thereby, the network bridge may be controlled by a so caller grid control portion of the power converter controller.

[0036] According to a further embodiment of the invention a reference signal for the amount of power to be generated by the wind turbine is used for controlling a AC-to-DC conversion being carried out in a generator bridge. This means that the described control method also takes into account a general power reference for the wind turbine, which may be given for instance by a superordinate wind farm controller controlling the general operation of a plurality of wind turbines of a wind farm. This may provide the advantage that the described control method may contribute to maintain the amount of power being generated by the wind turbine at a predetermined level.

[0037] According to a further aspect of the invention there is provided a control system for controlling a DC link voltage of a power converter connecting an electric generator of a wind turbine with a power grid. The provided control system comprises (a) a first determining unit for determining the rotational speed of a rotor of the electric generator, (b) a second determining unit for determining a strength of harmonic components of the rotational speed of the rotor, wherein the harmonic components have frequency components being different from a fundamental rotational frequency of the electric generator, (c) a third determining unit for determining a damping reference signal as a function of the determined strength of the harmonic components, and (d) a control unit for controlling the DC link voltage of the power converter in response to the determined damping reference signal.

[0038] Also the described control system is based on the idea that by controlling the DC link voltage of a power converter, mechanical oscillations of a wind turbine and in particular mechanical oscillations of a drive train of the

wind turbine can be effectively reduced.

[0039] It is mentioned that depending on the specific application the described units of the control system may be physically different units or may be realized within at least one combined unit.

[0040] According to an embodiment of the invention the control system is realized by a power converter controller for controlling the operation of the power converter. Thereby, the power converter controller comprises (a) a first portion for controlling the operation of a generator bridge carrying out a AC-to-DC conversion within the power converter and (b) a second portion for controlling the operation of a network bridge carrying out a DC-to-AC conversion within the power converter.

[0041] Since the described generator bridge is assigned to the electric generator side or the wind turbine side of the power converter, the first portion is often denominated a generator controller. Accordingly, since the described network bridge is assigned to the power grid side of the power converter, the second portion is often denominated a (power) grid controller.

[0042] According to a further aspect of the invention there is provided a computer program for controlling a DC link voltage of a power converter connecting an electric generator of a wind turbine with a power grid. The computer program, when being executed by a data processor, is adapted for carrying out the method as set forth in any one of the preceding claims.

[0043] As used herein, reference to a computer program is intended to be equivalent to a reference to a program element and/or to a computer readable medium containing instructions for controlling a computer system to coordinate the performance of the above described method.

[0044] The computer program may be implemented as computer readable instruction code in any suitable programming language, such as, for example, JAVA, C++, and may be stored on a computer-readable medium (removable disk, volatile or non-volatile memory, embedded memory/processor, etc.). The instruction code is operable to program a computer or any other programmable device to carry out the intended functions. The computer program may be available from a network, such as the World Wide Web, from which it may be downloaded.

[0045] The invention may be realized by means of a computer program respectively software. However, the invention may also be realized by means of one or more specific circuits respectively hardware. Furthermore, the invention may also be realized in a hybrid form, i.e. in a combination of software modules and hardware modules.

[0046] It has to be noted that embodiments of the invention have been described with reference to different subject matters. In particular, some embodiments have been described with reference to method type claims whereas other embodiments have been described with reference to apparatus type claims. However, a person skilled in the art will gather from the above and the following description that, unless other notified, in addition to any combination of features belonging to one type of subject matter also any combination between features relating to different subject matters, in particular between features of the method type claims and features of the apparatus type claims is considered as to be disclosed with this document.

[0047] The aspects defined above and further aspects of the present invention are apparent from the examples of embodiment to be described hereinafter and are explained with reference to the examples of embodiment. The invention will be described in more detail hereinafter with reference to examples of embodiment but to which the invention is not limited. Brief Description of the Drawing

Figure 1 shows a drive train damping controller, which provides a damping power reference signal being used by different control systems representing embodiments of the invention described in this document.

Figure 2 shows a control system for a drive train damping procedure, wherein in accordance with a first embodiment of the invention a DC link voltage control is carried out by a generator control portion of a power converter controller.

Figure 3 shows a control system for a drive train damping procedure, wherein in accordance with a second embodiment of the invention a DC link voltage control is carried out by a generator control portion of a power converter controller.

Figure 4 shows a control system for a drive train damping procedure, wherein in accordance with a third embodiment of the invention a DC link voltage control is carried out by a grid control portion of a power converter controller.

Figure 5 shows a diagram depicting an intermediate dip in the amount of power being transferred from a wind turbine to a power grid, which in accordance with a prior art damping procedure causes (a) a short rise in the voltage of the DC link of a power converter and (b) successive oscillations of the amount of transferred.

Figure 6 shows a diagram depicting an intermediate dip in the amount of power being transferred from a wind turbine to a power grid, which in accordance with a damping procedure described in this document causes (a) a short rise in the voltage of the DC link of a power converter followed by successive oscillations of the voltage of the DC link and (b) a comparatively smooth behavior of the amount of transferred power after the end of the intermediate dip.

Figure 7 shows a drive train damping controller, which provides a damping torque reference signal being used by different control systems representing embodiments of the invention described in this document.

Figure 8 shows a control system comprising the drive train damping controller of Figure 7, wherein a DC link voltage control is carried out by a generator control portion of a power converter controller.

Figure 9 shows a control system comprising the drive train damping controller of Figure 7, wherein a DC link voltage control is carried out by a grid control portion of a power converter controller.

Detailed Description

[0048] The illustration in the drawing is schematically. It is noted that in different figures, similar or identical elements are provided with the same reference signs or with reference signs, which are different from the corresponding reference signs only within the first digit.

[0049] Figure 1 shows a drive train damping controller 110, which provides a damping power reference signal P_{DTD} being used by different control systems representing embodiments of the invention described in this document.

[0050] The drive train damping controller 110 comprises a high pass filter 112, which receives as an input signal ω_g the actual rotational speed of the rotor of an electric generator (not depicted) of a wind turbine (also not depicted). The actual rotational speed ω_g may be measured for instance by means of an encoder and/or any type of speed/position observer and/or estimator.

[0051] According to the embodiment described here the high pass filter 112 is realized by a low pass filer 112a, a bypass line 112b and a subtracting unit 112c. Further, the output signal of the high pass filter 112 is fed to an amplifier 114, which has a predetermined gain. In Figure 1 this gain is denominated as "damping gain" (DampGain).

[0052] As can be seen from Figure 1, the output signal provided by the amplifier 114 is supplied to a limiting unit 116, which limits the output signal P_{DTD} of the whole drive train damping controller 110 within a range extending from $-P_{dtd_Lim}$ to $+P_{dtd_Lim}$. Limiting the damping power reference signal P_{DTD} within a predefined range provides the advantage that an unwanted oversteer by the control systems, which are described further below, can be avoided. According to the embodiment described here the limit values $-P_{dtd_Lim}$ and $+P_{dtd_Lim}$ for the damping power reference signal P_{DTD} depend on the nominal power of the respective wind turbine.

[0053] It is mentioned that the high pass filter in Figure 1 can be replaced by other type of filter or filter systems such as a band pass filter or a combination of several high pass filters.

[0054] Figure 2 shows a control system 200 of a power converter controller (not depicted) for a drive train damping procedure. The control system 200 comprises two portions, a first portion 202, which is also denominated a generator control portion or in short a generator controller, and a second portion 204, which is also denominated a grid control portion or in short a grid controller. According to the embodiment described here, a DC link voltage control is carried out by the generator controller 202 of the power converter controller.

[0055] The control system 200 comprises the drive train damping controller 110, which is illustrated in Figure 1 and which has been described above in detail. The damping power reference signal P_{DTD}, which is provided by the drive train damping controller 110 in response to the actual measured and/or observed rotational speed ω_g of the rotor (not depicted) of the electric generator (also not depicted), is supplied to a calculation unit 222 for calculating a reference signal V_{ACREF} for the harmonic voltage. This calculation is carried out in consideration of a signal V_{DC} being indicative for the actually measured DC link voltage.

[0056] As can be seen from Figure 2, the reference signal V_{ACREF} for the harmonic voltage being provided by the calculation unit 222 is fed to an adding unit 224, which adds the signal V_{ACREF} to a signal V_{DCREF} representing a reference signal for the fundamental voltage of the DC link of the power converter. The output signal from the adding unit 224 is fed, together with the above described (measured) DC link voltage V_{DC}, to a DC link controller 250. In response to the output signal of the adding unit 224 and to the signal V_{DC}, the DC link controller 250 determines a reference signal P_{GenRef} for the power to be generated by the electric generator.

[0057] Further, the signal P_{GenRef} is fed to a calculation unit 262 for calculating a generator current reference signal I_{dqrefm} representing the reference signal for the amount of current to be generated by the electric generator. Based on this signal I_{dqrefm} and on a signal I_{dqm} representing the measured current generated actually by the electric generator, a generator current controller 264 determines a reference voltage signal V_{dqm} for a Pulse Width Modulation (PWM) of an AC-to-DC conversion being carried out in a generator bridge (not depicted) of the power converter.

[0058] It is mentioned that the power reference signal P_{GenRef} with could also be replaced by a torque reference signal T_{GenRef}. Further details are given below with reference to the description of Figures 7, 8 and 9.

[0059] It is further mentioned that the indexes "dq" are indicative for the so called direct quadrature or in short d-q rotating reference frame, which is associated with a common mathematical transformation being often used to simplify the analysis of three-phase electric circuits. In the case of balanced three-phase electric circuits, application of the d-q transformation reduces the three AC quantities to two DC quantities. As a consequence, simplified calculations can be carried out on these imaginary

DC quantities before performing the inverse transform to recover the actual three-phase AC results.

[0060] The grid control portion 204 shown in Figure 2 comprises a calculation unit 272 for calculating a power grid current reference signal I_{dqrefg} in response to a reference signal P_{WTCRef} for the total power to be generated by the respective wind turbine. The reference signal P_{WTCRef} may be received for instance from a wind turbine controller (not depicted), which in known manner controls the operation of the whole wind turbine.

[0061] The signal I_{dqrefg}, which is indicative for the amount of current being supposed to be received by the power grid (not depicted), is supplied to a grid current controller 274. As can be seen from Figure 2, in response to the signal I_{dqrefg} and further in response to a signal I_{dqg} representing the measured current, which is actually received by the power grid, the grid current controller 274 determines a reference voltage signal V_{dqg}, which is a reference voltage signal for the Pulse Width Modulation (PWM) of a DC-to-AC conversion being carried out in a network bridge of the power converter.

[0062] Descriptive speaking, in the described control system 200 the change of DC link voltage reference V_{DCREF} corresponding to the damping power P_{DTD} is calculated. The DC link voltage reference V_{DCREF} with both DC component and harmonics is sent to the DC link controller 250. The output of the DC link controller 250 is the generator power reference P_{GenRef}. The generator power is controlled to follow this reference by the generator current controller 264 which is the inner loop of the generator controller.

[0063] The described control system 200 is in particular suitable when resonance frequency is relatively low due to the limitation of bandwidth of the DC link controller 250.

[0064] Figure 3 shows a control system 300 for a drive train damping procedure, wherein in accordance with the control system 200 the DC link voltage control is also carried out by the generator control portion 202 of the respective power converter controller. Compared to the control system 200 the control system 300 is more suitable when the mechanical resonance frequency of the comparatively high (e.g. more than 20 Hz).

[0065] As can be easily seen from a comparison of Figure 2 and Figure 3, there are significant similarities between the two control systems 200 and 300. For the sake of conciseness of this document, in the following focus is made to the differences between the two control systems 200 and 300.

[0066] The output signal P_{DTD} of the drive train damping controller 110 is added by an adding unit 352 to the output P_{DCRef} of the DC link controller 250 directly. The signal P_{DCRef} can be understood as a reference signal for the fundamental power to be generated by the electric generator.

[0067] The measured feedback signal V_{DC} of the DC link voltage is filtered by a band stop filter 340 so that the DC link controller 250 has no response to harmonic voltages of the DC link at resonance frequencies.

[0068] Figure 4 shows a control system 400 for a drive train damping procedure, wherein by contrast to the embodiments described above, the DC link voltage control is carried out by a grid control portion 204 of the respective power converter controller.

[0069] Again, there are many similarities between the control system 400 and the two control systems 200 and 300 described above. Therefore, in the following it will be focused on the differences between the two control systems 300 and 400.

[0070] As can be seen from Figure 4, the reference signal P_{WTCRef} for the power to be generated by the wind turbine is sent from a non depicted wind turbine controller to an adding unit 454 of the generator controller 202. The adding unit 454 adds (a) the damping power reference signal P_{DTD} to (b) the reference signal P_{WTCRef}, the result of which is the reference signal P_{GenRef} for the power to be generated by the electric generator.

[0071] As can be further seen from Figure 4, in the grid controller 204 the DC link controller 250 determines, in response to (a) the reference signal V_{DCREF} for the fundamental voltage of the DC link of the power converter and to (b) the output signal of the band stop filter 340, a reference signal $P_{GridRef}$ for the amount of power to be received by the power grid.

[0072] It is again mentioned that in some applications it might be advantageous to replace the band stop filter 340 by low-pass filter.

[0073] Figure 5 shows a diagram 580 depicting the time dependency 582 of the amount of power being transferred from the electric generator of a wind turbine to the power grid, when a conventional control procedure for controlling the operation of a power converter connecting the electric generator and the power grid is employed.

[0074] As can be seen from Figure 5, in case an intermediate dip 584 in the power curve 582 occurs (for instance due to an unwanted voltage dip in the power grid), a short rise 594 in the time dependency of the DC link voltage 590 appears. As can be further seen from Figure 5, after the end of the power dip 584, comparatively strong power oscillations 586 at the mechanical resonance frequency of the drive train of the wind turbine in the power curve 582 occur. These oscillations 586 are only slowly damped in time.

[0075] Figure 6 shows a corresponding diagram 680, which shows the same situation of a power dip 684 in the time dependency 682 of the amount of power being actually transferred from the electric generator to the power grid via the power converter, when a damping procedure in accordance with a control system as described in this document is employed.

[0076] Reference numeral 690 denominates the time dependency of the DC link voltage of the power converter. Again, the power dip 684 causes a short rise 694 of the DC link voltage 690. However, by contrast to the situation shown in Figure 5, now there appear no oscillations in the power signal 680 after the end of the dip.

Instead, damped oscillations 696 having again the frequency of the mechanical resonance of the drive train, appear in the time dependency 690 of the DC link voltage.

[0077] Figure 7 shows a drive train damping controller 710, which provides a damping torque reference signal T_{DTD} being used by different control systems representing embodiments of the invention described in this document. The structure of the drive train damping controller 710 corresponds to the structure of the drive train damping controller 110 shown in Figure 1. The only difference is that the output of the drive train damping controller 710 is the damping torque reference signal T_{DTD} and not a damping power reference signal P_{DTD}. Accordingly, a limiting unit 716 is used, which limits the output signal T_{DTD} of the whole drive train damping controller 710 within a range extending from $-T_{dtd_Lim}$ to $+T_{dtd_Lim}$.

[0078] It is mentioned that the high pass filter in Figure 7 can be replaced by other type of filter or filter systems such as a band pass filter or a combination of several high pass filters.

[0079] Figure 8 shows a control system 800 comprising the drive train damping controller 710 shown in Figure 7. The structure of the control system 800 corresponds to the structure of the control system 300 shown in Figure 3. Also the control system 800 comprises two portions, a first portion 802, which is also denominated a generator control portion or in short a generator controller, and a second portion 804, which is also denominated a grid control portion or in short a grid controller. According to the embodiment described here, a DC link voltage control is carried out by the generator controller 802 of the power converter controller.

[0080] As can be seen from a comparison between the control system 800 and the control system 300 shown in Figure 3, in the adding unit 352 there is added the damping torque reference signal T_{DTD} provided by the drive train damping controller 710 and a reference signal T_{DCRef} provided by the DC link controller 250. The reference signal T_{DCRef} is indicative for the fundamental torque which is supposed to be generated by the electric generator. Further, the output of the adding unit 352 is a reference signal T_{GenRef} for the amount of torque to be generated by the electric generator.

[0081] Apart from these differences the structures and the operations of the control system 800 and the control system 300 shown in Figure 3 correspond to each other. Therefore, for the sake of conciseness at this point of the description reference can be made to the description above.

[0082] Figure 9 shows a control system 900 comprising the drive train damping controller 710, wherein a DC link voltage control is carried out by the grid control portion 804 of a power converter controller. The structure of the control system 900 corresponds to the structure of the control system 400 shown in Figure 4. The only difference is that by means of the adding unit 454 there is added the damping torque reference signal T_{DTD} provided by the drive train damping controller 710 and a reference signal T_{WTCRef} for the torque to be generated by the electric generator. The reference signal T_{WTCRef} may be provided in particular by a non depicted wind turbine controller.

[0083] The output of the adding unit 454 is the reference signal T_{GenRef}, which has already been described above with reference to the control system 800. The reference signal T_{GenRef} is indicative for the amount of torque to be generated by the electric generator.

[0084] Apart from these differences the structures and the operations of the control system 900 and the control system 400 shown in Figure 4 correspond to each other. Therefore, for the sake of conciseness of this document at this point of the description reference can be made to the description above.

[0085] The above elucidated embodiments of the invention presented in this document may in particular provide the following advantages:

(A) Oscillation of torque and speed of the drive train, in particular of the blades, of the wind turbine can be damped actively.
(B) Power oscillations are not forwarded to the power grid.
(C) An implementation of the invention into actual available power converters can be realized by means of software. Therefore, there are no or only a negligible additional costs for realizing the invention in connection with available wind turbines.

[0086] It should be noted that reference signs in the claims should not be construed as limiting the scope of the claims.

Claims

1. A method for controlling a DC link voltage of a power converter connecting an electric generator of a wind turbine with a power grid, the method comprising
determining the rotational speed (ω_g) of a rotor of the electric generator,
determining a strength of harmonic components of the rotational speed (ω_g) of the rotor, wherein the harmonic components have frequency components being different from a fundamental rotational frequency of the electric generator,
determining a damping reference signal (P_{DTD}, T_{DTD}) as a function of the determined strength of the harmonic components,
filtering a measurement signal (V_{DC}) being indicative for the actual DC link voltage (V_{DC}) with a filter (340), which is capable of suppressing at least partially frequency components corresponding to mechanic resonance frequencies of a drive train of the wind turbine, and
controlling the DC link voltage (V_{DC}) of the power converter in response to

(a) the determined damping reference signal (P_{DTD}, T_{DTD}) and in further response to
(b) the filtered measurement signal.

2. The method as set forth in the preceding claim, wherein determining the strength of harmonic components of the rotational speed (ω_g) of the rotor comprises
receiving a signal being indicative for the actual rotational speed (ω_g) of the rotor and
filtering the signal with a further filter (112), which is capable of suppressing at least partially frequency components corresponding to the fundamental rotational frequency.

3. The method as set forth in the preceding claim, wherein determining the damping reference signal (P_{DTD}, T_{DTD}) comprises
receiving the filtered signal from the further filter (112) and
limiting the strength the received filtered signal.

4. The method as set forth in any one of the preceding claims, wherein
controlling the DC link voltage (V_{DC}) of the power converter is carried out in further response to
a reference signal (V_{DCREF}) for the DC link voltage (V_{DC}).

5. The method as set forth in any one of the preceding claims, wherein
controlling the DC link voltage (V_{DC}) comprises
controlling an AC-to-DC conversion being carried out in a generator bridge of the power converter.

6. The method as set forth in the preceding claim, wherein a reference signal (P_{WTCRef}) for the amount of power to be generated by the wind turbine is used for controlling a DC-to-AC conversion being carried out in a network bridge.

7. The method as set forth in any one of the preceding claims, wherein
controlling the DC link voltage comprises
controlling a DC-to-AC conversion being carried out in a network bridge of the power converter.

8. The method as set forth in the preceding claim, wherein a reference signal (P_{WTCRef}) for the amount of power to be generated by the wind turbine is used for controlling a AC-to-DC conversion being carried out in a generator bridge.

9. A control system for controlling a DC link voltage of a power converter connecting an electric generator of a wind turbine with a power grid, the control system (200, 300, 400, 800, 900) comprising
a first determining unit for determining the rotational speed (ω_g) of a rotor of the electric generator,
a second determining unit for determining a strength of harmonic components of the rotational speed (ω_g) of the rotor, wherein the harmonic components have frequency components being different from a fundamental rotational frequency of the electric generator,
a third determining unit for determining a damping reference signal (P_{DTD}, T_{DTD}) as a function of the determined strength of the harmonic components,
a filtering unit (340) for filtering a measurement signal (V_{DC}) being indicative for the actual DC link voltage (V_{DC}), wherein the filtering unit (340) is capable of suppressing at least partially frequency components corresponding to mechanic resonance frequencies of a drive train of the wind turbine, and
a control unit for controlling the DC link voltage (V_{DC}) of the power converter in response to

(a) the determined damping reference signal (P_{DTD}, T_{DTD}) and in further response to
(b) the filtered measurement signal.

10. The control system as set forth in the preceding claim, wherein
the control system (200, 300, 400) is realized by a power converter controller for controlling the operation of the power converter, the power converter controller comprising a first portion (202) for controlling the operation of a generator bridge carrying out a AC-to-DC conversion within the power converter and a second portion (204) for controlling the operation of a network bridge carrying out a DC-to-AC conversion within the power converter.

11. A computer program for controlling a DC link voltage of a power converter connecting an electric generator of a wind turbine with a power grid, the computer program, when being executed by a data processor, is adapted for carrying out the method as set forth in any one of the claims 1 to 8.

Patentansprüche

1. Verfahren zur Steuerung einer Zwischenkreis-Gleichspannung eines Leistungsumformers, der einen elektrischen Generator einer Windkraftanlage mit einem Stromnetz verbindet, wobei das Verfahren umfasst:

Bestimmen der Drehzahl (ω_g) eines Rotors des elektrischen Generators,
Bestimmen einer Intensität von harmonischen Komponenten der Drehzahl (ω_g) des Rotors, wobei die harmonischen Komponenten Frequenzkomponenten aufweisen, die von einer Grunddrehzahl des elektrischen Generators verschieden sind,

Bestimmen eines Dämpfungsreferenzsignals (P_{DTD}, T_{DTD}) als eine Funktion der bestimmten Intensität der harmonischen Komponenten,
Filtern eines Messsignals (V_{DC}), das für die Ist-zwischenkreis-Gleichspannung (V_{DC}) indikativ ist, mit einem Filter (340), welches in der Lage ist, wenigstens teilweise Frequenzkomponenten zu unterdrücken, die mechanischen Resonanzfrequenzen eines Antriebsstrangs der Windkraftanlage entsprechen, und
Steuern der zwischenkreis-Gleichspannung (V_{DC}) des Leistungsumformers in Reaktion auf

(a) das bestimmte Dämpfungsreferenzsignal (P_{DTD}, T_{DTD}) und weiterhin in Reaktion auf
(b) das gefilterte Messsignal.

2. Verfahren nach dem vorhergehenden Anspruch, wobei das Bestimmen der Intensität von harmonischen Komponenten der Drehzahl (ω_g) des Rotors umfasst:

Empfangen eines Signals, das für die Istdrehzahl (ω_g) des Rotors indikativ ist, und
Filtern des Signals mit einem weiteren Filter (112), welches in der Lage ist, wenigstens teilweise
Frequenzkomponenten zu unterdrücken, die der Grunddrehzahl entsprechen.

3. Verfahren nach dem vorhergehenden Anspruch, wobei das Bestimmen des Dämpfungsreferenzsignals (P_{DTD}, T_{DTD}) umfasst:

Empfangen des gefilterten Signals von dem weiteren Filter (112), und
Begrenzen der Stärke des empfangenen gefilterten Signals.

4. Verfahren nach einem der vorhergehenden Ansprüche, wobei das Steuern der zwischenkreis-Gleichspannung (V_{DC}) des Leistungsumformers ferner durchgeführt wird in Reaktion auf ein Referenzsignal (V_{DCREF}) für die zwischenkreis-Gleichspannung (V_{DC}).

5. Verfahren nach einem der vorhergehenden Ansprüche, wobei das Steuern der zwischenkreis-Gleichspannung (V_{DC}) umfasst:

Steuern einer AC-DC-Wandlung, die in einer Generatorbrücke des Leistungsumformers durchgeführt wird.

6. Verfahren nach dem vorhergehenden Anspruch, wobei ein Referenzsignal (P_{WTCRef}) für die Menge an durch die Windkraftanlage zu erzeugender Energie verwendet wird, um eine DC-AC-Wandlung zu steuern, die in einer Netzbrücke durchgeführt wird.

7. Verfahren nach einem der vorhergehenden Ansprüche, wobei das Steuern der zwischenkreis-Gleichspannung (V_{DC}) umfasst:

Steuern einer DC-AC-Wandlung, die in einer Netzbrücke des Leistungsumformers durchgeführt wird.

8. Verfahren nach dem vorhergehenden Anspruch, wobei ein Referenzsignal (P_{WTCRef}) für die Menge an durch die Windkraftanlage zu erzeugender Energie verwendet wird, um eine AC-DC-Wandlung zu steuern, die in einer Generatorbrücke durchgeführt wird.

9. Steuerungssystem zur Steuerung einer Zwischenkreis-Gleichspannung eines Leistungsumformers, der einen elektrischen Generator einer Windkraftanlage mit einem Stromnetz verbindet, wobei das Steuerungssystem (200, 300, 400, 800, 900) umfasst:

eine erste Bestimmungseinheit zum Bestimmen der Drehzahl (ω_g) eines Rotors des elektrischen Generators,
eine zweite Bestimmungseinheit zum Bestimmen einer Intensität von harmonischen Komponenten der Drehzahl (ω_g) des Rotors, wobei die harmonischen Komponenten Frequenzkomponenten aufweisen, die von einer Grunddrehzahl des elektrischen Generators verschieden sind,
eine dritte Bestimmungseinheit zum Bestimmen eines Dämpfungsreferenzsignals (P_{DTD}, T_{DTD}) als eine Funktion der bestimmten Intensität der harmonischen Komponenten,
eine Filtereinheit (340) zum Filtern eines Messsignals (V_{DC}), das für die Ist-Zwischenkreis-Gleichspannung (V_{DC}) indikativ ist, wobei die Filtereinheit (340) in der Lage ist, wenigstens teilweise Frequenzkomponenten zu unterdrükken, die mechanischen Resonanzfrequenzen eines Antriebsstrangs der Windkraftanlage entsprechen, und
eine Steuereinheit zum Steuern der Zwischenkreis-Gleichspannung (V_{DC}) des Leistungsumformers in Reaktion auf

(a) das bestimmte Dämpfungsreferenzsignal (P_{DTD}, T_{DTD}) und weiterhin in Reaktion auf
(b) das gefilterte Messsignal.

10. Steuerungssystem nach dem vorhergehenden Anspruch, wobei das Steuerungssystem (200, 300, 400) durch eine Leistungsumformer-Steuereinrich-

tung zum Steuern des Betriebs des Leistungsumformers realisiert ist, wobei die Leistungsumformer-Steuereinrichtung umfasst:

einen ersten Abschnitt (202) zum Steuern des Betriebs einer Generatorbrücke, die eine AC-DC-Wandlung innerhalb des Leistungsumformers durchführt, und
einen zweiten Abschnitt (204) zum Steuern des Betriebs einer Netzbrücke, die eine DC-AC-Wandlung innerhalb des Leistungsumformers durchführt.

11. Computerprogramm zur Steuerung einer Zwischenkreis-Gleichspannung eines Leistungsumformers, der einen elektrischen Generator einer Windkraftanlage mit einem Stromnetz verbindet, wobei das Computerprogramm, wenn es durch einen Datenprozessor ausgeführt wird, geeignet ist, das Verfahren nach einem der Ansprüche 1 bis 8 auszuführen.

Revendications

1. Procédé de contrôle d'une tension de liaison CC d'un convertisseur de puissance connectant un générateur électrique d'une éolienne avec un réseau électrique, le procédé comprenant
la détermination de la vitesse de rotation (ω_g) d'un rotor du générateur électrique,
la détermination d'une force de composantes harmoniques de la vitesse de rotation (ω_g) du rotor, dans lequel les composantes harmoniques ont des composantes de fréquence étant différentes d'une fréquence de rotation fondamentale du générateur électrique,
la détermination d'un signal de référence d'amortissement (P_{DTD}, T_{DTD}) comme une fonction de la force déterminée des composantes harmoniques,
le filtrage d'un signal de mesure (V_{DC}) étant indicateur pour la tension de liaison CC (V_{DC}) réelle avec un filtre (340), qui est apte à supprimer au moins partiellement des composantes de fréquence correspondant à des fréquences de résonance mécanique d'une chaîne dynamique de l'éolienne, et
le contrôle de la tension de liaison CC (V_{DC}) du convertisseur de puissance en réponse

(a) au signal de référence d'amortissement (P_{DTD}, T_{DTD}) déterminé et en outre en réponse
(b) au signal de mesure filtré.

2. Procédé selon la revendication précédente, dans lequel la détermination de la force de composantes harmoniques de la vitesse de rotation (ω_g) du rotor comprend
la réception d'un signal étant indicateur de la vitesse de rotation réelle (ω_g) du rotor et
le filtrage du signal avec un autre filtre (112), qui est apte à supprimer au moins partiellement des composantes de fréquence correspondant à la fréquence de rotation fondamentale.

3. Procédé selon la revendication précédente, dans lequel la détermination du signal de référence d'amortissement (P_{DTD}, T_{DTD}) comprend
la réception du signal filtré de l'autre filtre (112) et la limitation de la force du signal filtré reçu.

4. Procédé selon l'une quelconque des revendications précédentes, dans lequel
le contrôle de la tension de liaison CC (V_{DC}) du convertisseur de puissance est effectué en outre en réponse à un signal de référence (V_{DCREF}) pour la tension de liaison CC (V_{DC}).

5. Procédé selon l'une quelconque des revendications précédentes, dans lequel
le contrôle de la tension de liaison CC (V_{DC}) comprend
le contrôle d'une conversion CA à CC étant effectuée dans un pont de générateur du convertisseur de puissance.

6. Procédé selon la revendication précédente, dans lequel un signal de référence (P_{WTCRef}) pour la quantité de puissance devant être générée par l'éolienne est utilisé pour contrôler une conversion CC à CA étant effectuée dans un pont de réseau.

7. Procédé selon l'une quelconque des revendications précédentes, dans lequel
le contrôle de la tension de liaison CC comprend
le contrôle d'une conversion CC à CA étant effectuée dans un pont de réseau du convertisseur de puissance.

8. Procédé selon la revendication précédente, dans lequel un signal de référence (P_{WTCRef}) pour la quantité de puissance devant être générée par l'éolienne est utilisé pour contrôler une conversion CA à CC étant effectuée dans un pont de générateur.

9. Système de contrôle pour contrôler une tension de liaison CC d'un convertisseur de puissance connectant un générateur électrique d'une éolienne avec un réseau électrique, le système de contrôle (200, 300, 400, 800, 900) comprenant
une première unité de détermination pour déterminer la vitesse de rotation (ω_g) d'un rotor du générateur électrique,
une deuxième unité de détermination pour déterminer une force de composantes harmoniques de la vitesse de rotation (ω_g) du rotor, dans lequel les composantes harmoniques ont des composantes de fréquence étant différentes d'une fréquence de rotation

fondamentale du générateur électrique,
une troisième unité de détermination pour déterminer un signal de référence d'amortissement (P_{DTD}, T_{DTD}) comme une fonction de la force déterminée des composantes harmoniques,
une unité de filtrage (340) pour filtrer un signal de mesure (V_{DC}) étant indicateur pour la tension de liaison CC (V_{DC}) réelle, dans lequel l'unité de filtrage (340) est apte à supprimer au moins partiellement des composantes de fréquence correspondant à des fréquences de résonance mécanique d'une chaîne dynamique de l'éolienne, et
une unité de contrôle pour contrôler la tension de liaison CC (V_{DC}) du convertisseur de puissance en réponse

(a) au signal de référence d'amortissement (P_{DTD}, T_{DTD}) déterminé et en outre en réponse
(b) au signal de mesure filtré.

10. Système de contrôle selon la revendication précédente, dans lequel
le système de contrôle (200, 300, 400) est réalisé par un contrôleur de convertisseur de puissance pour contrôler le fonctionnement du convertisseur de puissance, le contrôleur de convertisseur de puissance comprenant une première partie (202) pour contrôler le fonctionnement d'un pont de générateur effectuant une conversion CA à CC à l'intérieur du convertisseur de puissance et
une deuxième partie (204) pour contrôler le fonctionnement d'un pont de réseau effectuant une conversion CC à CA à l'intérieur du convertisseur de puissance.

11. Programme informatique pour contrôler une tension de liaison CC d'un convertisseur de puissance connectant un générateur électrique d'une éolienne avec un réseau électrique, le programme informatique, lorsqu'il est exécuté par un processeur de données, est adapté à mettre en oeuvre le procédé selon l'une quelconque des revendications 1 à 8.

FIG 1

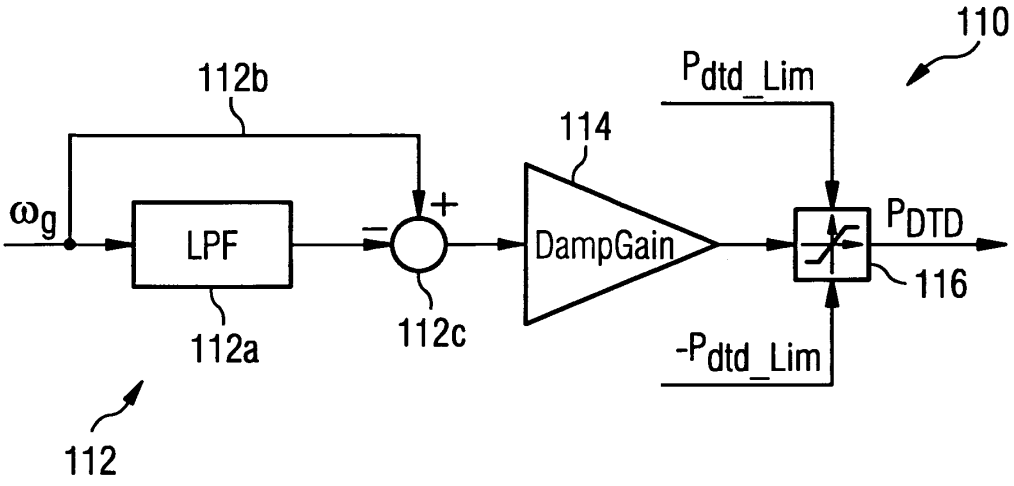
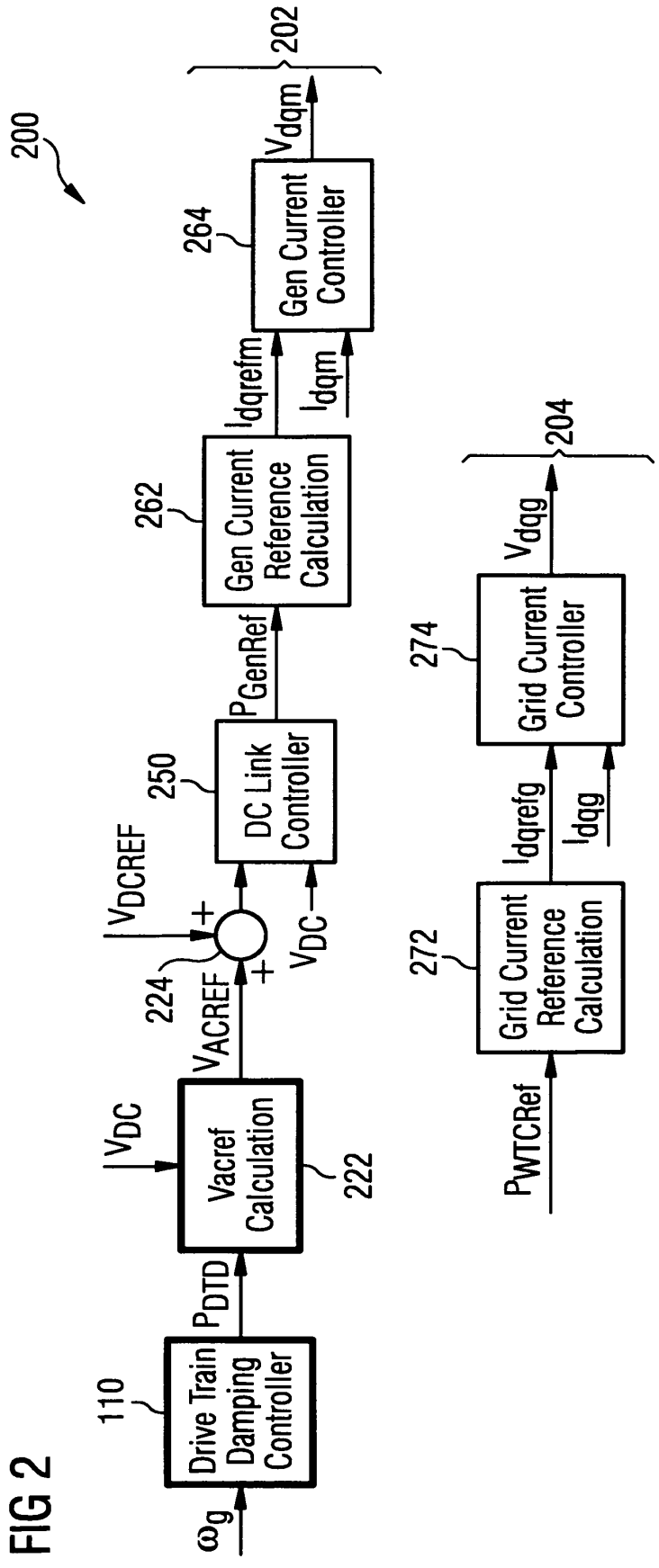

110
112b
P_{dtd_Lim}
114
ω_g
LPF
+
−
DampGain
P_{DTD}
116
112a
112c
$-P_{dtd_Lim}$
112

FIG 2


200
202
264
Gen Current Controller
V_{dqm}
I_{dqrefm}
I_{dqm}
262
Gen Current Reference Calculation
P_{GenRef}
250
DC Link Controller
V_{DCREF}
224
V_{ACREF}
V_{DC}
V_{DC}
Vacref Calculation
222
P_{DTD}
110
Drive Train Damping Controller
ω_g
204
V_{dqg}
274
Grid Current Controller
I_{dqrefg}
I_{dqg}
272
Grid Current Reference Calculation
P_{WTCRef}

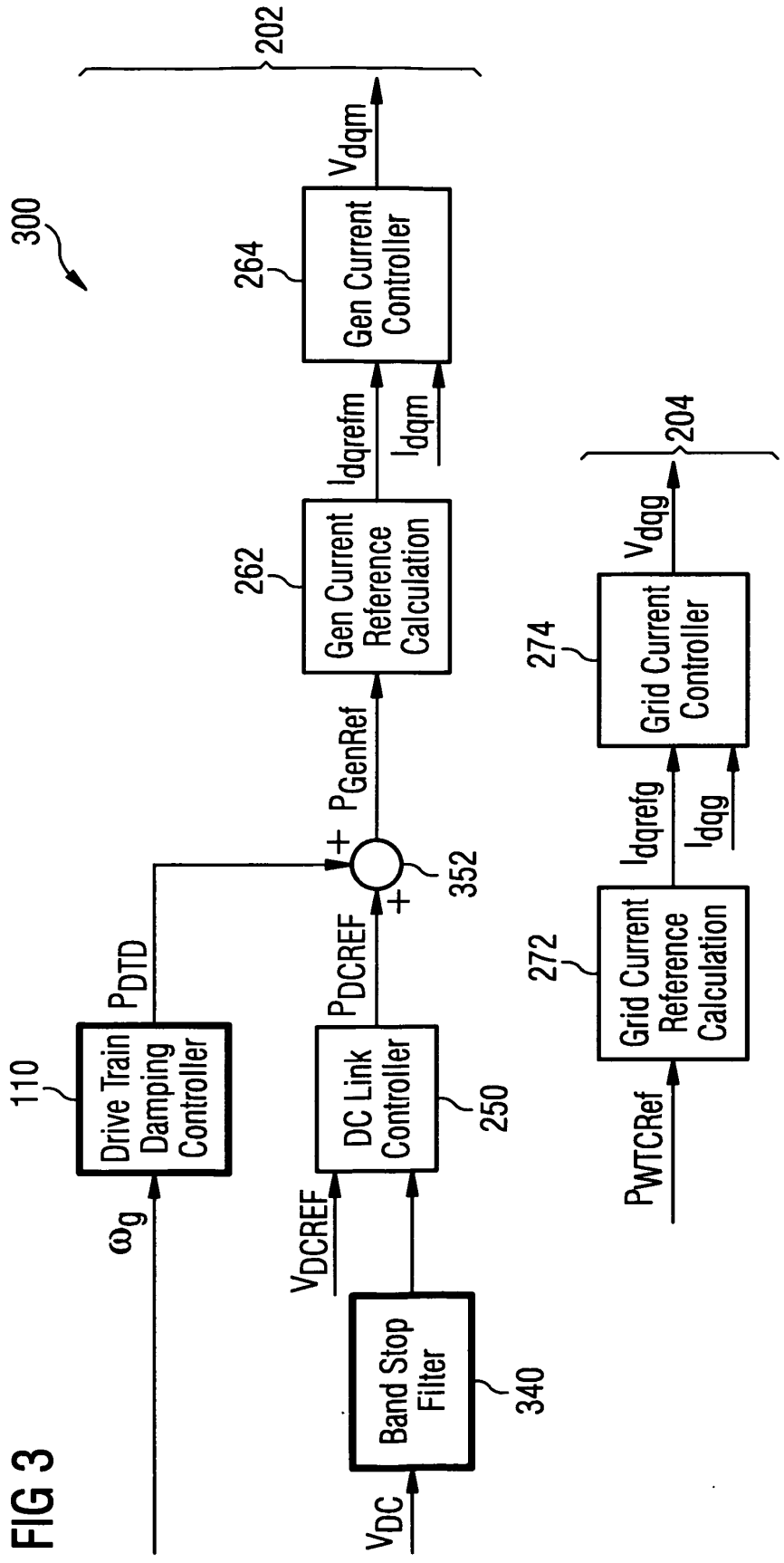

300
202
264
Gen Current Controller
V_{dqm}
I_{dqrefm}
I_{dqm}
262
Gen Current Reference Calculation
P_{GenRef}
352
+
+
P_{DTD}
P_{DCREF}
110
Drive Train Damping Controller
DC Link Controller
250
ω_g
V_{DCREF}
Band Stop Filter
340
V_{DC}
204
274
Grid Current Controller
V_{dqg}
I_{dqrefg}
I_{dqg}
272
Grid Current Reference Calculation
P_{WTCRef}

FIG 3

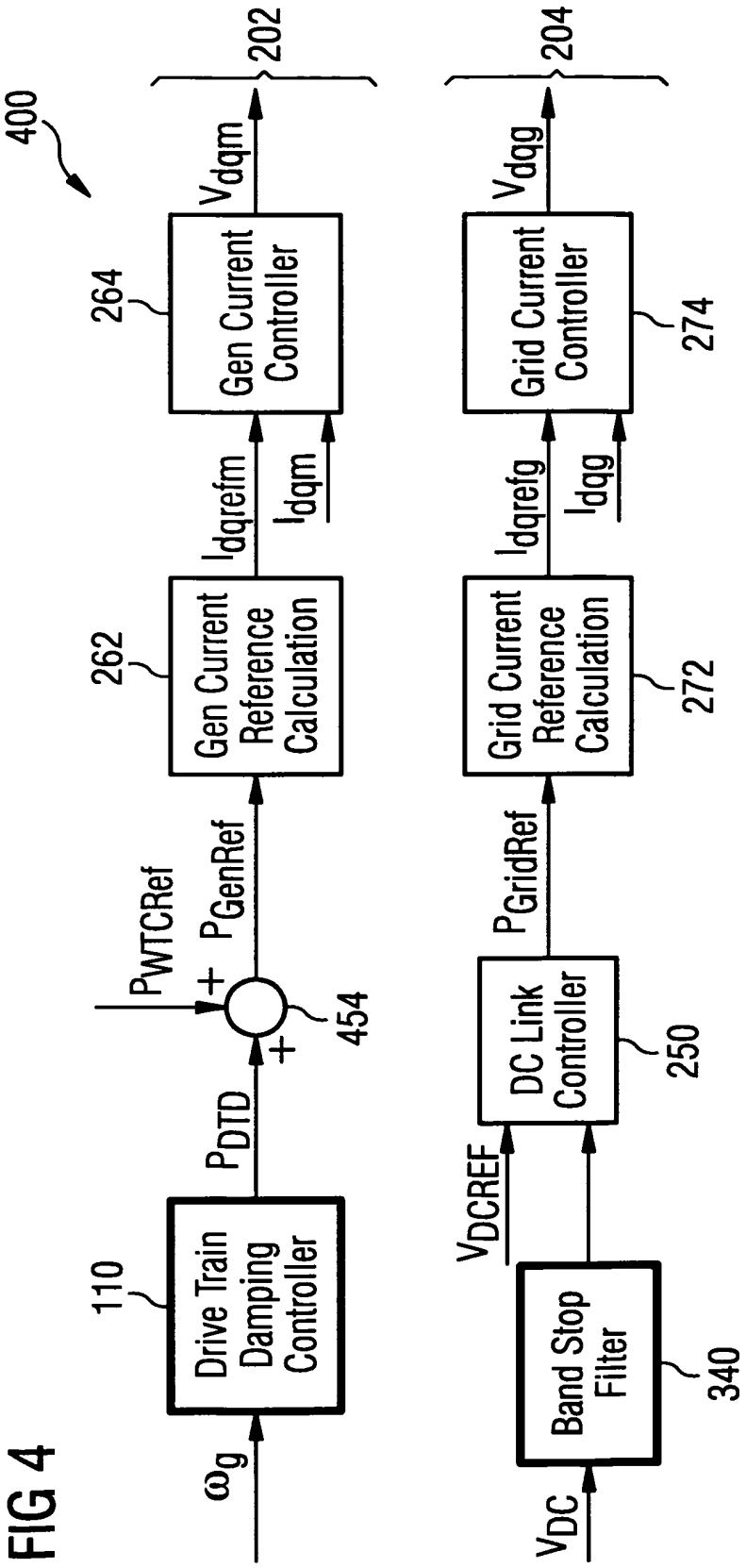

400
202
204
264
Gen Current Controller
V_{dqm}
V_{dqg}
Grid Current Controller
274
I_{dqrefm}
I_{dqm}
I_{dqrefg}
I_{dqg}
262
Gen Current Reference Calculation
Grid Current Reference Calculation
272
P_{WTCRef}
P_{GenRef}
$P_{GridRef}$
+
+
454
110
Drive Train Damping Controller
P_{DTD}
V_{DCREF}
DC Link Controller
250
ω_g
Band Stop Filter
340
V_{DC}

FIG 4

FIG 5

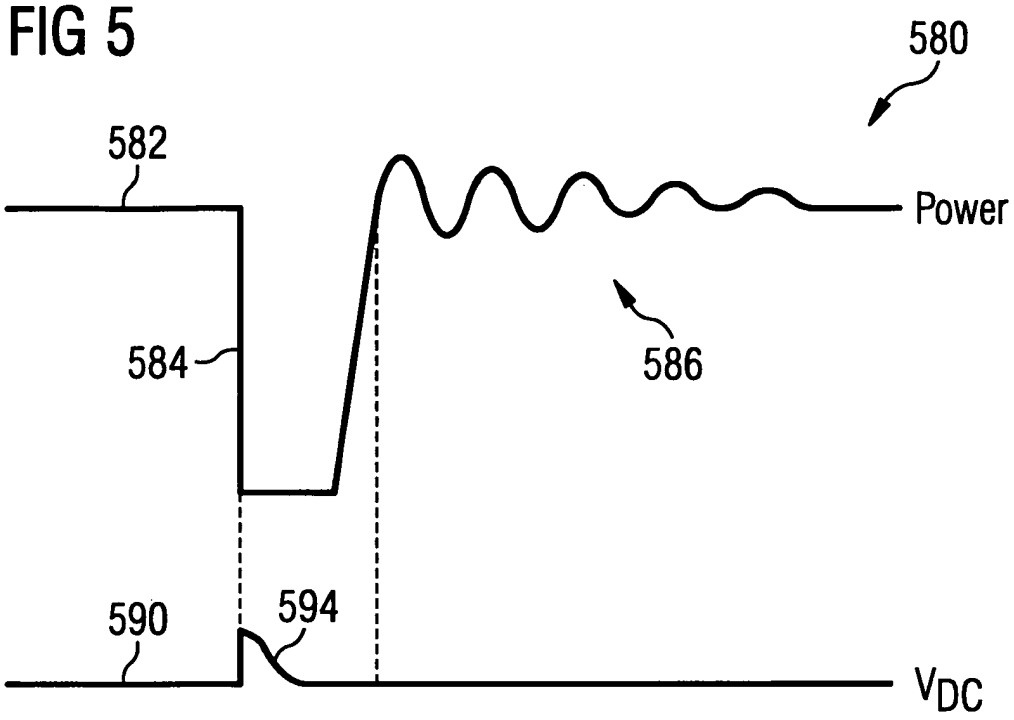

580
582
Power
584
586
590
594
V_{DC}

FIG 6

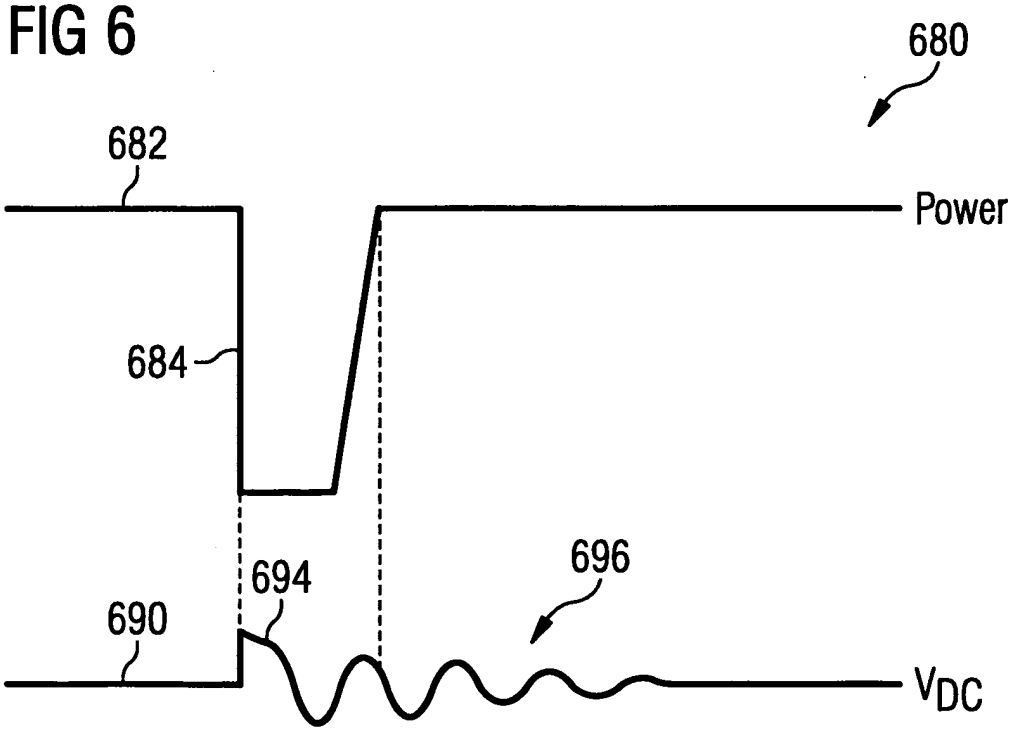
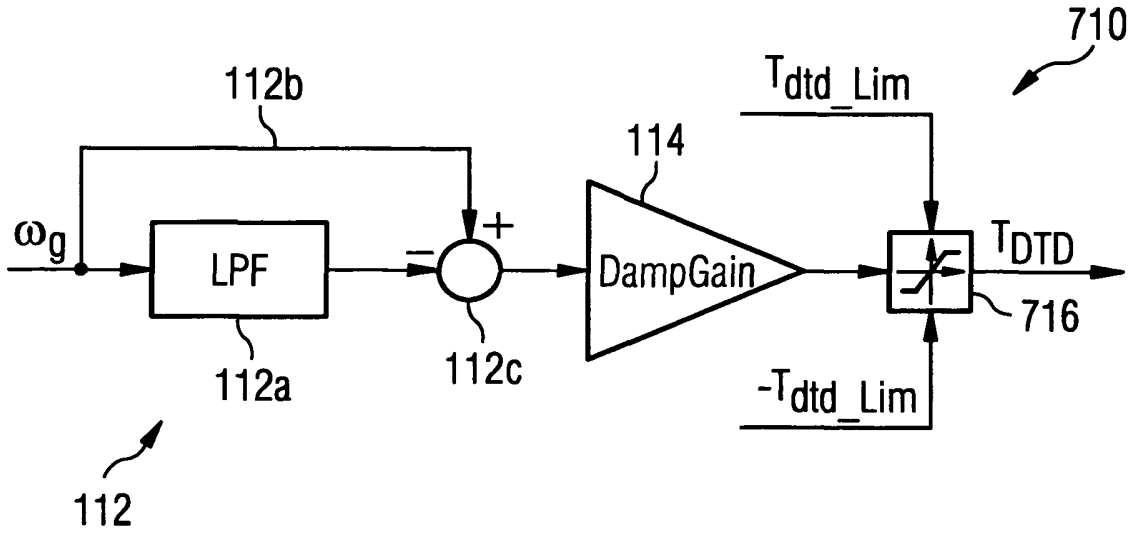

680
682
Power
684
694
696
690
V_{DC}

FIG 7


710
112b
T_{dtd_Lim}
114
ω_g
LPF
+
−
DampGain
T_{DTD}
716
112a
112c
$-T_{dtd_Lim}$
112

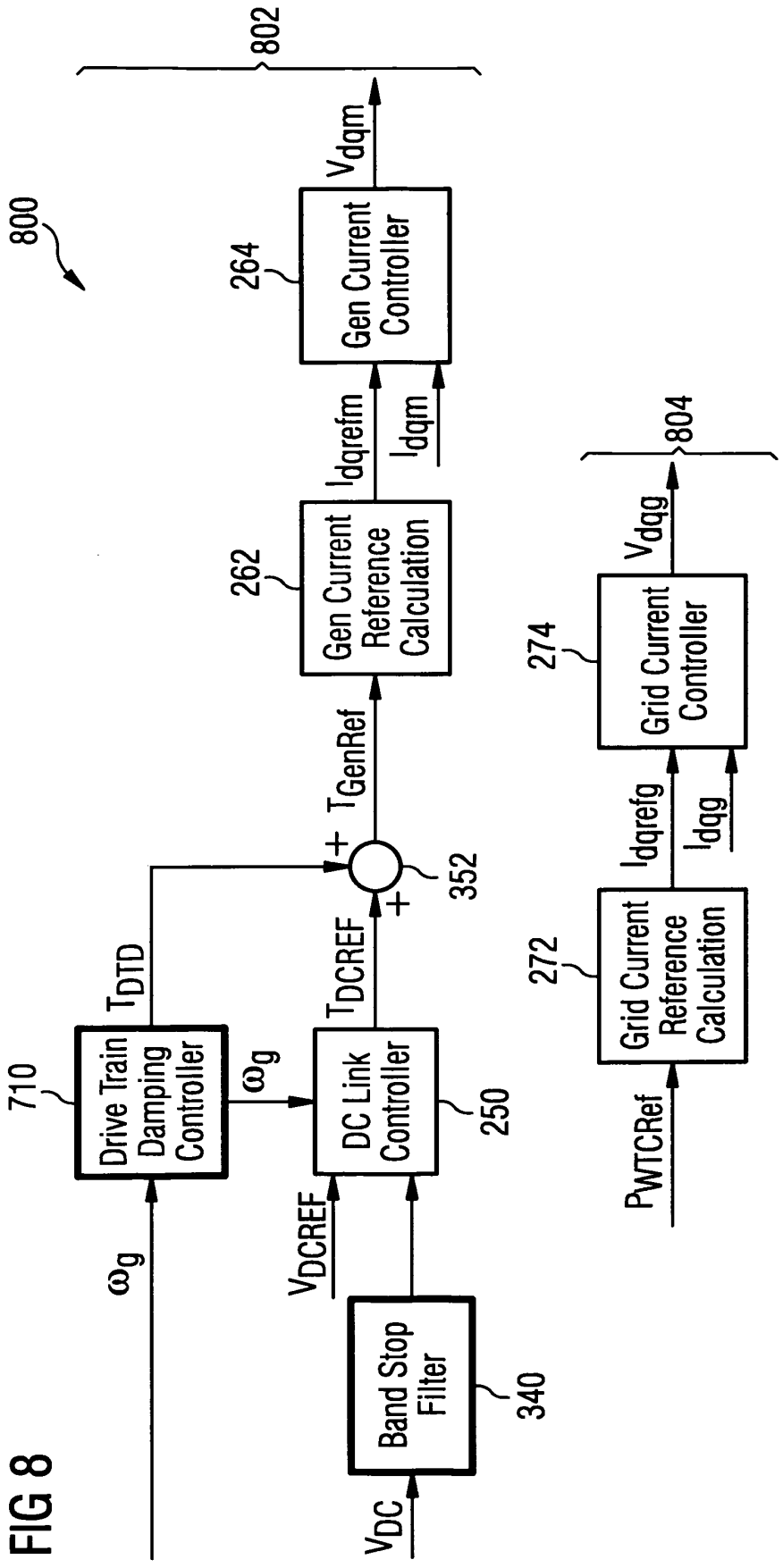
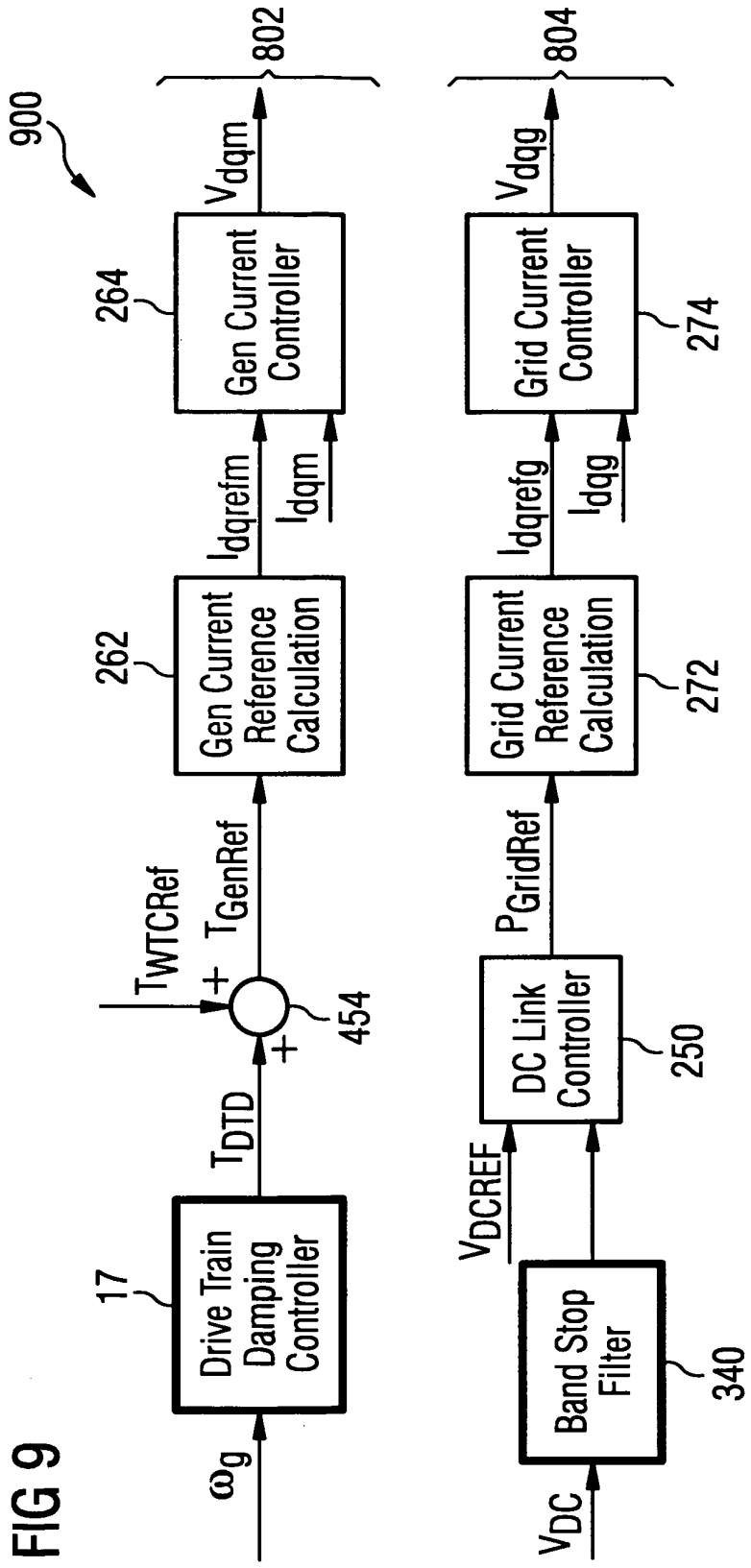

800
802
804
710
Drive Train Damping Controller
250
DC Link Controller
340
Band Stop Filter
262
Gen Current Reference Calculation
264
Gen Current Controller
272
Grid Current Reference Calculation
274
Grid Current Controller
352
ω_g
ω_g
T_{DTD}
T_{DCREF}
T_{GenRef}
V_{DCREF}
V_{DC}
I_{dqrefm}
I_{dqm}
V_{dqm}
I_{dqrefg}
I_{dqg}
V_{dqg}
P_{WTCRef}
+
+

FIG 8

FIG 9


900
802
804
V_{dqm}
V_{dqg}
264
Gen Current Controller
Grid Current Controller
274
I_{dqrefm}
I_{dqm}
I_{dqrefg}
I_{dqg}
262
Gen Current Reference Calculation
Grid Current Reference Calculation
272
T_{WTCRef}
T_{GenRef}
$P_{GridRef}$
454
+
+
T_{DTD}
17
Drive Train Damping Controller
DC Link Controller
250
V_{DCREF}
ω_g
Band Stop Filter
340
V_{DC}

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- Multi-pole permanent magnet synchronous generator wind turbines' grid support capability in uninterrupted operation during grid faults. *IET Renew. Power Giener.,* 2009, vol. 3 (3), 333-348 **[0001]**